THz RADIATION SOURCE THROUGH PERIODICALLY MODULATED STRUCTURES

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CONTRACT NO. N68171-96-C-9015

4 th Interim Report

September 1996 - November 1996

" The research reported in this document has been made possible through the support and sponsorship of the U.S. Government through its European Research Office of the U.S. Army. This report is intended only for the internal management use of the Contractor and the U.S. Government."

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB NO. 0704-0188*

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	January 15, 1997	Interim, September 1996 - November 1996

4. TITLE AND SUBTITLE

THz Radiation Source Trough Periodically Modulated Structures

5. FUNDING NUMBERS

C
N 68171-96-C-9015

6. AUTHOR(S)

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8. PERFORMING ORGANIZATION REPORT NUMBER

4th Interim Report

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U.S. Army Research Office
P.O. Box 12211
Research Triangle Park, NC 27709-2211

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

WK2Q6C-7372-EE01

11. SUPPLEMENTARY NOTES

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12a. DISTRIBUTION / AVAILABILITY STATEMENT	12 b. DISTRIBUTION CODE
Approved for public release; distribution unlimited.	

13. ABSTRACT *(Maximum 200 words)*

While the previous period was dedicated to studies of undoped field free GaAs/GaAlAs short period superlattices with different well widths, we have concentrated our activities in the 4th period of this project on the study of combinations of different superlattices using an advanced technique of hot electron spectroscopy. The basic idea of this structure is the developement of a new injection structure which will allow the realization of an inverted population in a well defined superlattice subband.

The semiconductor superlattices under investigation consist of a periodic sequence of alternately grown thin layers of GaAs and AlGaAs. The sophisticated technology of Molecular Beam Epitaxy (MBE) gives us the possibility to fabricate artificial monocrystalline semiconductors with desirable minibands and minigaps. Once a well defined quantummechanical structure with extremely narrow potential barriers (in the order of 10 atomic layers) is grown in a controlled manner, the transport of electrons in the structure is largely governed by quantum states. With this structure we are able to demonstrate that injection of carriers in possible in a well defined miniband, transition to a lower state and extraction again through a miniband. This is a key experiment for the generation of THz eission between two minibands.

In the next period we will systematically study the transport in a biased miniband of a superlattice.

14. SUBJECT TERMS	15. NUMBER IF PAGES
Carrier injection, quantum wires, THz sources, superlattice spectroscopy	
	16. PRICE CODE

17. SECURITY CLASSIFICATION OR REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

REPORT DOCUMENTATION PAGE (SF298)
(Continuation Sheet)

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Electron transport through a combination of different superlattices

In this report we summarize the results obtained by hot electron spectroscopy of combinations of field free undoped superlattices. The study was carried out using a modified tunneling hot electron transfer amplifier, with an injector consisting of a tunneling barrier embedded within two highly doped GaAs contact layers. An energy tunable electron beam is injected into the structure under investigation. The measured static transfer ratio is defined by the ballistic electron current measured at the collector of the three terminal device devided by the emitter current ($a=I_C/I_E$). Since the transfer ratio is proportional to the transmittance of the structure, which is grown between the base and the collector contact, we get important informations of the transport mechanism in such sophisticated quantum mechanical systems.

The samples grown by Molecular Beam Epitaxy we have studied consist of the following common features: A highly doped n^+-GaAs collector contact layer ($n=1x10^{18}cm^{-3}$) is grown on a semiinsulating GaAs substrate. Followed by the heterostructure under investigation and the drift regions which are slightly n-doped ($\sim 5x10^{14}$ cm^{-3}), in order to avoid undesired band bending. This layers are followed by a highly doped ($2x10^{18}cm^{-3}$) n^+-GaAs layer (base) of 13 nm width. On top of the base layer a 13 nm undoped $Ga_{0.7}Al_{0.3}As$ barrier is grown followed by a spacer and a n^+-GaAs layer, nominally doped to $n=3x10^{17}$ cm^{-3}. Finally, a n^+-GaAs contact layer ($n=1x10^{18}cm^{-3}$) is grown on top of the heterostructure to form the emitter. The full width at half maximum (FWHM) of the injected energy distribution was measured to be 17 meV in width using a resonant tunneling diode in the drift region. It should be noted that the FWHM limits the energy resolution.

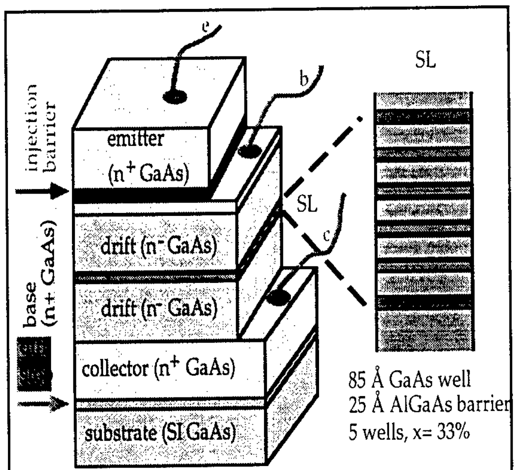

Figure 1. Three terminal device

The fabrication (Fig. 1) of the three terminal device includes the following steps: $SiCl_4/SF_6$ reactive ion etching (RIE), unselective etching to the collector layer, metallization of the AuGeNi ohmic contacts, Si_3N_4 isolation of the emitter mesa (PECVD), and finally the metallization of the CrAu bonding pads. More details can be found elsewhere[i].

We have grown two samples with different combinations of five period superlattices. The superlattice growth parameters are given in table 1.

sample No.	superlattice 1		superlattice 2		superlattice 3	
	barrier (Å)	well (Å)	barrier (Å)	well (Å)	barrier (Å)	well (Å)
1	35	42.5	25	120		
2	35	42.5	25	120	15	85

Sample No. 1 consist of two superlattices. The parameters were chosen in such way that the lowest miniband of the first superlattice is aligned with the second miniband of the second superlattice. Injected electrons with energies high enough to traverse into the lower miniband of the first superlattice have two output channels. One channel is defined by transport through the second miniband of the second superlattice without scattering. Electrons which are scattered in the second miniband can be collected via transport through the first miniband of the second superlattice.

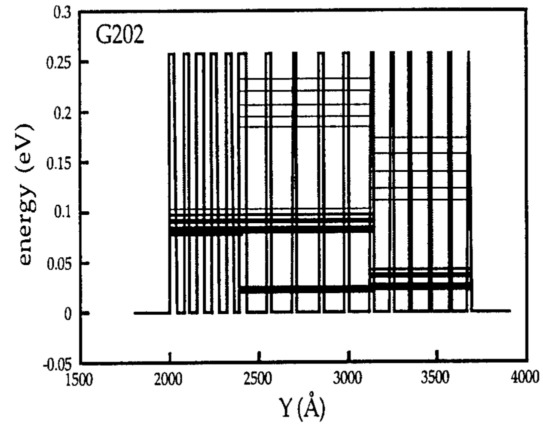

Figure 2. Bandstructure of a combination of three different superlattices

Sample No. 2 consist of three different superlattices as noted in the table. The conduction band structure is sketched in Figure 2. The first and the second superlattice have the same parameters as the superlattices in sample No. 1. The third superlattice is designed such that the minigap between the first and the second miniband is aligned with the second miniband of superlattice 2. The first minibands of superlattice two and three are aligned as well. Consequently only electrons which are scattered in the second superlattice can be collected and measured in the collector current. Electrons that are reflected by the minigap and not scattered into the first miniband will be bounced back and collected at the base layer.

In figure 3 the transfer ratio a versus injection energy is shown. A sharp increase of the transfer ratio is evident at about 90 meV which corresponds to the position of the first miniband of superlattice 1. It can be seen that the transfer ratio of sample No. 2 is about 50 % of the transfer ratio of sample No. 1. Consequently we assume that about half of the electrons injected into the second miniband of the second superlattice are scattered into the first miniband. Since the energy gap between the second and the lowest miniband is of the order of an longitudinal optical (LO) phonon, we know that the interminiband transition is mainly governed by LO-phonon scattering which is the most effective scattering process at low temperatures. If the minigap is smaller than 36 meV one might achieve inversion and consequently a light emitting device. The design of such structure is even more sophisticated. A prototype of a sample mentioned above is already grown and will be characterized soon.

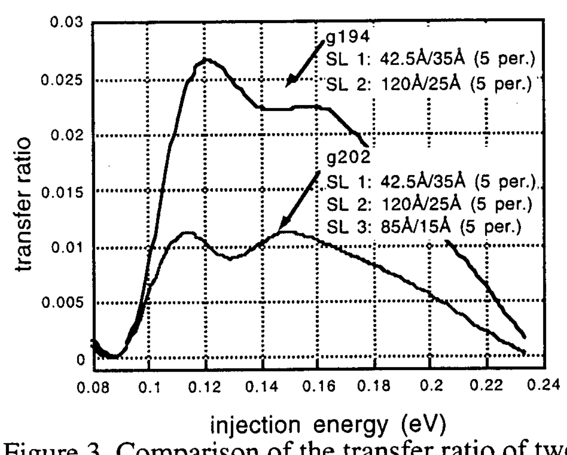

Figure 3. Comparison of the transfer ratio of two different combinations of superlattices

Future work:

Detection of plasmon emission in a 4-terminal device (spontaneous emission).

Stimulated by the work on laser-pulse induced THz emission from plasmons, observed recently by the Vienna group (to be published), *an experiment is proposed and designed* in cooperation with Prof. Bakshi and Kempa from Boston College to *observe directly the relaxation of hot carrier distribution via plasmon emission*. This is similar to an experiment which demonstrated the LO phonon replica. The fundamental question here is weather a well defined energy spectrum due to bulk plasmon relaxation can be observed.

A new *four-terminal device* scheme is designed which might be capable of demonstrating the above process. We are aware that several groups have tried to demonstrate plasmon relaxation as an efficient energy relaxation channel. However, no conclusive results have been published, to our knowledge, so far.

The suggested four terminal device which is based on the growth on n+ substrate and application of several etch-stop layers, allows for an independent variation of the injection energy and the analyser (both consisting of a resonant tunnelling filters). The open question here is weather it will be possible to grow structures of sufficient quality (long enough mean free path for impurity scatterings) to provide the necessary energy resolution required here.

The demonstration of a controlled plasmon relaxation is a bench- mark experiment on the way to a plasmon mediated THz source.

[i] C. Rauch, G. Strasser, K. Unterrainer, and E. Gornik, Appl. Phys. Lett. **70** (1997)

B. Brill and M. Heiblum, Phys. Rev. B **49**, 14762 (1994)

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